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The intertemporal relation between expected return and risk on currency

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ABSTRACT

The literature has so far focused on the risk-return tradeoff in equity markets and ignored alternative risky assets. This paper examines the presence and significance of an intertemporal relation between expected return and risk in the foreign exchange market. The paper provides new evidence on the intertemporal capital asset pricing model by using high-frequency intraday data on currency and by presenting significant time-variation in the risk aversion parameter. Five-minute returns on the spot exchange rates of the U.S. dollar vis-à-vis six major currencies (the Euro, Japanese Yen, British Pound Sterling, Swiss Franc, Australian Dollar, and Canadian Dollar) are used to test the existence and significance of a daily risk-return tradeoff in the FX market based on the GARCH, realized, and range volatility estimators. The results indicate a positive, but statistically weak relation between risk and return on currency.

Key words: foreign exchange market, ICAPM, high-frequency data, time-varying risk aversion, daily realized volatility.

JEL classification: G12, C13, C22

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I. Introduction

Merton's (1973) intertemporal capital asset pricing model (ICAPM) indicates that the conditional expected excess return on a risky market portfolio is a linear function of its conditional variance plus a hedging component that captures the investor's motive to hedge for future investment opportunities. Merton (1980) shows that the hedging demand component becomes negligible under certain conditions and the equilibrium relation between risk and return is defined as:

$$E_t(R_{t+1}) = \beta \cdot E_t(\sigma^2_{t+1}), \quad (1)$$

where $E_t(R_{t+1})$ and $E_t(\sigma^2_{t+1})$ are, respectively, the conditional mean and variance of excess returns on a risky market portfolio, and $\beta > 0$ is the risk aversion parameter of market investors. Equation (1) establishes the dynamic relation that investors require a larger risk premium at times when the market is riskier.

Many studies investigate the significance of an intertemporal relation between expected return and risk in the aggregate stock market. However, the existing literature has not yet reached an agreement on the existence of a positive risk-return tradeoff for stock market indices.[1] Due to the fact that the conditional mean and volatility of the market portfolio are not observable, different approaches, different data sets and sample periods used by previous studies in estimating the conditional mean and variance are largely responsible for the contradictory empirical evidence.

The prediction of Merton (1973, 1980) that expected returns should be related to conditional risk applies not only to the stock market portfolio but also to any risky portfolio. However, earlier studies have so far focused on the risk-return tradeoff in equity markets and ignored other risky financial assets. Although there are a few studies testing the significance of a time-series relation between risk and return in international equity markets, the focus is generally on the U.S. stock market. It is also important to note that earlier studies assume a constant risk-return tradeoff and ignore time-variation in the risk aversion parameter β.[2] This paper examines the intertemporal relation between expected return and risk in currency markets. The paper not only investigates ICAPM in the foreign exchange market, but examines the significance of time-varying risk aversion as well.

The foreign exchange market includes the trading of one currency against another between large banks, central banks, currency speculators, multinational corporations, governments, and other financial markets and institutions. The FX market is an inter-bank or inter-dealer network first established in 1971 when many of the world's major currencies moved towards floating exchange rates. It is considered an

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[1] See French, Schwert, and Stambaugh (1987), Campbell (1987), Nelson (1991), Campbell and Hentschel (1992), Chan, Karolyi, and Stulz (1992), Glosten, Jagannathan and Runkle (1993), Scruggs (1998), Harvey (2001), Goyal and Santa-Clara (2003), Brandt and Kang (2004), Ghysels, Santa-Clara and Valkanov (2005), Bali and Peng (2006), Christoffersen and Diebold (2006), Guo and Whitelaw (2006), Lundblad (2007), and Bali (2008).

[2] A few exceptions are Chou, Engle and Kane (1992), Harvey (2001), and Lettau and Ludvigson (2004).

over-the-counter (OTC) market, meaning that transactions are conducted between two counter parties that agree to trade via telephone or electronic network. Because foreign exchange is an OTC market where brokers/dealers negotiate directly with one another, there is no central exchange or clearing house.[3]

The FX market has grown rapidly since the early 1990s. According to the triennial central bank surveys conducted by the Bank for International Settlements (BIS), the April 2007 data show an unprecedented rise in activity in traditional foreign exchange markets compared to 2004. As shown in Table 1, average daily turnover rose to US $3.1 trillion in April 2007, an increase of 69% (compared to April 2004) at current exchange rates and 63% at constant exchange rates.[4] Since April 2001, average daily turnover in foreign exchange markets worldwide (adjusted for cross-border and local double-counting and evaluated at April 2007 exchange rates) increased by 58% and 69% between two consecutive triennial surveys. Comparing the average daily turnovers of US $500 billion in 1988 and US $3.1 trillion in 2007 indicates that trading volume in FX markets increased by more than five times over the past two decades.

The FX market has become the world's largest financial market, and it is not uncommon to see over US $3 trillion traded each day. By contrast, the New York Stock Exchange (NYSE)— the world's largest equity market with daily trading volumes in the US $60 to $80 billion dollar range—is positively dwarfed when compared to the FX market. Daily turnover in FX markets is now more than ten times the size of the combined daily turnover on all the world's equity markets. Even when combining the US bond and equity markets, total daily volumes still do not come close to the values traded on the currency market.

The FX market is unique because of its trading volumes, the extreme liquidity of the market, the large number of, and variety of, traders in the market, its geographical dispersion, its long trading hours (24 hours a day except on weekends), the variety of factors that affect exchange rates, the low margins of profit compared with other markets of fixed income (but profits can be high due to very large trading volumes), and the use of leverage.

Earlier studies have so far focused on the U.S. stock market when investigating the ICAPM. However, with an average daily trading volume of US $3 trillion per day, Forex is far and away the most enormous financial market in the world, dwarfing the trading volumes of other markets. We contribute to the existing literature by examining for the first time the significance of an intertemporal relation between

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[3] As FX trading has evolved, several locations have emerged as market leaders. Currently, London contributes the greatest share of transactions with over 32% of the total trades. Other trading centers—listed in order of volume—are New York, Tokyo, Zurich, Frankfurt, Hong Kong, Paris, and Sydney. Because these trading centers cover most of the major time zones, FX trading is a true 24-hour market that operates five days a week.

[4] In addition to "traditional" turnover of US $3.1 trillion in global foreign exchange market, US $2.1 trillion was traded in currency derivatives.

expected return and risk on currency. We also test whether aggregate risk aversion in the FX market changes through time.

We utilize 5-minute returns on the spot exchange rates of the U.S. dollar vis-à-vis six major currencies (the Euro, Japanese Yen, British Pound Sterling, Swiss Franc, Australian Dollar, and Canadian Dollar) to construct the daily returns, realized volatility and range volatility estimators. Then, using the intraday data-based daily returns as well as the GARCH, realized, and range-based volatility measures we test for the presence and significance of a risk-return tradeoff in the FX market. By sampling the return process more frequently, we improve the accuracy of the conditional volatility estimate and measure the risk-return relationship at the daily level. When we assume a constant risk-return tradeoff in currency markets, we find a positive but statistically weak relation between expected return and risk on currency.

We estimate the dependence of expected returns on the lagged realized variance over time using rolling regressions. This also allows us to check whether our results are driven by a particular sample period. Two different rolling regression approaches provide strong evidence on the time-variation of risk aversion parameters for all currencies considered in the paper. However, the direction of a relationship between expected return and risk is not clear for the entire FX market.

The paper is organized as follows. Section II provides the descriptive statistics for the daily and five-minute returns on exchange rates as well as the daily realized and range-based volatility measures. Section III explains the estimation methodology. Section IV presents the empirical results on a constant risk-return tradeoff in the FX market. Section V examines the significance of time-varying risk aversion. Section VI investigates whether the covariances of individual exchange rates with the FX market are priced in currency market. Section VII concludes the paper.

II. Data

To test the significance of a risk-return tradeoff in currency markets, we use daily returns on the spot exchange rates of the U.S. dollar vis-à-vis six major currencies: the Euro (EUR), Japanese Yen (JPY), British Pound Sterling (GBP), Swiss Franc (CHF), Australian Dollar (AUD), and Canadian Dollar (CAD). According to the BIS (2007) study, on the spot market the most heavily traded currency pairs were EUR/USD (27%), JPY/USD (13%), GBP/USD (12%), AUD/USD (6%), CHF/USD (5%) and CAD/USD (4%). As reported in Table 2, the U.S. dollar has been the dominant currency in both the spot and the forward and the swap transactions. Specifically, the U.S. currency was involved in 88.7% of transactions, followed by the Euro (37.2%), the Japanese Yen (20.3%), the Pound Sterling (16.9%), the Swiss Franc (6.1%), Australian Dollar (5.5%), and Canadian Dollar (4.2%). The sum of the six major currencies (EUR, JPY, GBP, CHF, AUD, CAD) accounts for a market share approximately equal to that of the US Dollar (90.2%).[5]

The raw 5-minute data on six exchange rates (EUR/USD, JPY/USD, GBP/USD, CHF/USD, AUD/USD and CAD/USD) are obtained from Olsen and Associates. The full sample covers 2,282 days, from January 1, 2002 to March 31, 2008. Following Bollerslev and Domowitz (1993), and Andersen, Bollerslev, Diebold, and Labys (2001), we define the day as starting at 21:05 pm on one night and ending at 21:00 pm the next night. The total number of 5-minute observations for each exchange rate is therefore equal to $2{,}282 \times 288 = 657{,}216$. However, we are not able to use all of these observations because the trading activity in FX markets slows down substantially during the weekends and the major US official holidays. Following Andersen, Bollerslev, Diebold, and Labys (2001), along with the weekends, we removed the following holidays from our sample: Christmas (December 24-26), New Year's (December 31-January 2), July 4th, Good Friday, Easter Monday, Memorial Day, Labor Day, Thanksgiving Day and the day after. In addition to official holidays and weekends, we removed three days (March 4, 2002, April 14, 2003, and January 30, 2004) from our sample as these days contained the longest zero or constant 5-minute return sequences that might contaminate the daily return and variance estimates. As a result, we end up with a total of 1,556 daily observations.

Panel A of Table 3 presents the mean, median, maximum, minimum, standard deviation, skewness, kurtosis, and autoregressive of order one, AR(1), statistics for daily returns on the six exchange rates. The standard errors of the skewness and kurtosis estimates provide evidence that the empirical distributions of returns on exchange rates are generally symmetric and fat-tailed. More specifically, the skewness measures are statistically insignificant for all currencies, except for the Japanese Yen. The kurtosis measures are statistically significant without any exception. The Jarque-Bera, $JB = n[(S^2/6) + (K-3)^2/24]$, is a formal statistic with the Chi-square distribution for testing whether the returns are normally distributed, where n denotes the number of observations, S is skewness and K is kurtosis. The JB statistics indicate significant departures from normality for the empirical return distributions of six exchange rates. As expected, daily returns on exchange rates are not highly persistent, as shown by the negative AR(1) coefficients which are less than 0.10 in absolute value. Although the economic significance of the AR(1) coefficients is low, they are statistically significant at the 5% or 1% level for all currencies, except for the British Pound and Australian Dollar.

The daily intertemporal relation between expected return and risk on currency is tested using the daily realized variance of returns on exchange rates. In very early work, the daily realized variance of

[5] Note that volume percentages should add up to 200%; 100% for all the sellers and 100% for all the buyers. As shown in Table 2, the market shares of seven major currencies add up to 180%. The remaining 20% of the total (200%) market turnover has been accounted by other currencies from Europe and from other parts of the world.

asset returns is measured by the squared daily returns, where the asset return is defined as the natural logarithm of the ratio of consecutive daily closing prices. A series of papers by Andersen, Bollerslev, Diebold, and Ebens (2001), Andersen, Bollerslev, Diebold, and Labys (2001, 2003), and Andersen, Bollerslev, and Diebold (2004) indicate that these traditional measures are poor estimators of day-by-day movements in volatility, as the idiosyncratic component of daily returns is large. They demonstrate that the realized volatility measures based on intraday data provide a dramatic reduction in noise and a radical improvement in temporal stability relative to realized volatility measures based on daily returns. Andersen, Bollerslev, Diebold, and Labys (2003) show formally that the concept of realized variance is, according to the theory of quadratic variation and under suitable conditions, an asymptotically unbiased estimator of the integrated variance and thus it is a canonical and natural measure of daily return volatility.

Following the recent literature on integrated volatility, we use the high-frequency intraday data to construct the daily realized variance of exchange rates. To set forth notation, let P_t denote the time t ($t \geq 0$) exchange rate with the unit interval t corresponding to one day. The discretely observed time series process of logarithmic exchange rate returns with q observations per day, or a return horizon of $1/q$, is then defined by

$$R_{(q),t} = \ln P_t - \ln P_{t-1/q}\,, \tag{2}$$

where $t = 1/q, 2/q, \ldots$. We calculate the daily realized variance of exchange rates using the intraday high-frequency (five-minute) return data as

$$VAR_t^{realized} = \sum_{i=0}^{q_i - 1} R^2_{(q),t-i/q}\,, \tag{3}$$

where $q_{i,t}$ is the number of five-minute intervals on day t and $R_{i,t}$ is the logarithmic exchange rate return in five-minute interval i on date t.

On a regular trading day, there are 288 five-minute intervals. The exchange rate of the most recent record in a given five-minute interval is taken to be the exchange rate of that interval. A five-minute return is then constructed using the logarithmic exchange rate difference for a five-minute interval. With 1,556 days in our full sample, we end up with using a total of $1{,}556 \times 288 = 448{,}128$ five-minute return observations to calculate daily return and variance estimates.

Panel B of Table 3 presents the summary statistics of the daily realized variances of exchange rate returns. The average daily realized variance is 6×10^{-5} for AUD/USD, 4.31×10^{-5} for CHF/USD, 4.07×10^{-5} for JPY/USD, 3.60×10^{-5} for CAD/USD, 3.47×10^{-5} for EUR/USD, and 2.77×10^{-5} for GBP/USD. These measures correspond to an annualized volatility of 12.30% for AUD/USD, 10.42% for CHF/USD, 10.13% for JPY/USD, 9.52% for CAD/USD, 9.35% for EUR/USD, and 8.35% for GBP/USD.

A notable point in Panel B is that the daily realized variances are highly persistent, as shown by the AR(1) coefficients which are in the range of 0.49 to 0.64. Consistent with Andersen, Bollerslev, Diebold, Ebens (2001) and Andersen, Bollerslev, Diebold, Labys (2001), the distributions of realized variances are skewed to the right and have much thicker tails than the corresponding normal distribution.

Market microstructure noises in transaction data such as the bid-ask bounce may influence our risk measures based on the realized volatility and GARCH volatility forecasts, even though the data we use contain very liquid financial time series and thus are least subject to biases created by market microstructure effects. An alternative volatility measure that utilizes information contained in the high frequency intraday data is Parkinson's (1980) range-based estimator of the daily integrated variance:

$$VAR_t^{range} = 0.361\left[\ln(P_t^{\max}) - \ln(P_t^{\min})\right]^2, \tag{4}$$

where $P_t^{\max}$ and $P_t^{\min}$ are the maximum and minimum values of the exchange rate on day *t*. Alizadeh et al. (2002) and Brandt and Diebold (2006) show that the range-based volatility estimator is highly efficient, approximately Gaussian and robust to certain types of microstructure noise such as bid-ask bounce. In addition, range data are available for many assets over a long sample period.

Panel C of Table 3 presents the summary statistics of the daily range variances of exchange rate returns. The average daily range variance is 4.20×10^{-5} for AUD/USD, 3.56×10^{-5} for CHF/USD, 3.15×10^{-5} for JPY/USD, 2.63×10^{-5} for CAD/USD, 2.76×10^{-5} for EUR/USD, and 2.30×10^{-5} for GBP/USD. These measures correspond to an annualized volatility of 10.29% for AUD/USD, 9.47% for CHF/USD, 8.91% for JPY/USD, 8.14% for CAD/USD, 8.34% for EUR/USD, and 7.61% for GBP/USD. These results indicate that the daily realized volatility estimates are somewhat higher than the daily range volatilities. Another notable point in Panel C is that the daily range variances are less persistent than the daily realized variances. Specifically, the AR(1) coefficients are in the range of 0.09 to 0.34 for the daily range variances. Similar to our findings for the daily realized variances, the distributions of range variances are skewed to the right and have much thicker tails than the corresponding normal distribution.

III. Estimation Methodology

The following GARCH-in-mean process is used with the conditional normal density to model the intertemporal relation between expected return and risk on currency:

$$R_{t+1} \equiv \alpha + \beta \cdot \sigma_{t+1|t}^2 + \varepsilon_{t+1}, \tag{5}$$

$$\varepsilon_{t+1} = z_{t+1} \cdot \sigma_{t+1|t}, \quad z_{t+1} \sim N(0,1), \quad E(\varepsilon_{t+1}) = 0, \tag{6}$$

$$E(\varepsilon_{t+1}^2 \mid \Omega_t) = \sigma_{t+1|t}^2 = \gamma_0 + \gamma_1 \varepsilon_t^2 + \gamma_2 \sigma_t^2, \tag{7}$$

$$f(R_{t+1};\mu_{t+1|t},\sigma_{t+1|t})=\frac{1}{\sqrt{2\pi\sigma_{t+1|t}^2}}\exp\left[-\frac{1}{2}\left(\frac{R_{t+1}-\mu_{t+1|t}}{\sigma_{t+1|t}}\right)^2\right], \tag{8}$$

where R_{t+1} is the daily return on exchange rates for period t+1, $\mu_{t+1|t}\equiv\alpha+\beta\cdot\sigma_{t+1|t}^2$ is the conditional mean for period t+1 based on the information set up to time t, $\varepsilon_{t+1}=z_{t+1}\cdot\sigma_{t+1|t}$ is the error term with $E(\varepsilon_{t+1})=0$, $\sigma_{t+1|t}$ is the conditional standard deviation of daily returns on currency and $z_{t+1}\sim N(0,1)$ is a random variable drawn from the standard normal density and can be viewed as information shocks in the FX market. $\sigma_{t+1|t}^2$ is the conditional variance of daily returns based on the information set up to time t denoted by Ω_t. The conditional variance, $\sigma_{t+1|t}^2$, follows a GARCH(1,1) process as defined by Bollerslev (1986) to be a function of the last period's unexpected news (or information shocks), z_t, and the last period's variance, σ_t^2. $f(R_{t+1};\mu_{t+1|t},\sigma_{t+1|t})$ is the conditional normal density function of R_{t+1} with the conditional mean of $\mu_{t+1|t}$ and conditional variance of $\sigma_{t+1|t}^2$. Our focus is to examine the magnitude and statistical significance of the risk aversion parameter β in equation (5).

Campbell (1987) and Scruggs (1998) point out that the approximate relationship in equation (1) may be misspecified if the hedging term in ICAPM is important. To make sure that our results from estimating equation (5) are not due to model misspecification, we added to the specifications a set of control variables that have been used in the literature to capture the state variables that determine changes in the investment opportunity set. Several studies find that macroeconomic variables associated with business cycle fluctuations can predict the stock market.[6] The commonly chosen variables include Treasury bill rates, federal funds rate, default spread, term spread, and dividend-price ratios. We study how variations in the fed funds rate, default spread, and term spread affect the intertemporal risk-return relation.[7] Earlier studies also control for the lagged return in the conditional mean specification.

We obtain daily data on the federal funds rate, 3-month Treasury bill, 10-year Treasury bond yields, BAA-rated and AAA-rated corporate bond yields from the H.15 database of the Federal Reserve Board. The federal funds (*FED*) rate is the interest rate at which a depository institution lends immediately available funds (balances at the Federal Reserve) to another depository institution overnight. It is a closely watched barometer of the tightness of credit market conditions in the banking system and the stance of monetary policy. In addition to the fed funds rate, we use the term and default spreads as control variables. The term spread (*TERM*) is calculated as the difference between the yields on the 10-

[6] See Keim and Stambaugh (1986), Chen, Roll, and Ross (1986), Campbell and Shiller (1988), Fama and French (1988, 1989), Campbell (1987, 1991), Ghysels, Santa-Clara, and Valkanov (2005), and Guo and Whitelaw (2006).
[7] We could not include the aggregate dividend yield (or the dividend-price ratio) because the data on dividends are available only at the monthly frequency while our empirical analyses are based on the daily data.

year Treasury bond and the 3-month Treasury bill. The default spread (*DEF*) is computed as the difference between the yields on the BAA-rated and AAA-rated corporate bonds. We test the significance of the risk aversion parameter, β, after controlling for macroeconomic variables and lagged return:

$$R_{t+1} \equiv \alpha + \beta \cdot \sigma^2_{t+1|t} + \lambda_1 \cdot FED_t + \lambda_2 \cdot DEF_t + \lambda_3 \cdot TERM_t + \lambda_4 \cdot R_t + \varepsilon_{t+1}, \tag{9}$$

$$\varepsilon_{t+1} = z_{t+1} \cdot \sigma_{t+1|t}, \quad z_{t+1} \sim N(0,1), \quad E(\varepsilon_{t+1}) = 0, \tag{10}$$

$$E(\varepsilon^2_{t+1} \,|\, \Omega_t) = \sigma^2_{t+1|t} = \gamma_0 + \gamma_1 \varepsilon^2_t + \gamma_2 \sigma^2_t. \tag{11}$$

Earlier studies that investigate the daily risk-return tradeoff generally rely on the GARCH-in-mean methodology. In risk-return regressions, it is not common to use the realized variance measures obtained from the intraday data. In this paper, we first generate the daily realized variance based on the 5-minute returns on exchange rates and then estimate the following the risk-return regression:

$$R_{t+1} = \alpha + \beta \cdot E_t[VAR^{realized}_{t+1}] + \varepsilon_{t+1}, \tag{12}$$

where R_{t+1} is one-day ahead return on exchange rate and $E_t[VAR^{realized}_{t+1}]$ is proxied by the lagged realized variance measure, i.e., $E_t[VAR^{realized}_{t+1}] = VAR^{realized}_t$ defined in eq. (3). As reported in Panel B of Table 3, $VAR^{realized}_t$ has significant persistence measured by the first-order serial correlation that makes $VAR^{realized}_t$ reasonable proxy for the one-day ahead expected realized variance. The slope coefficient β in eq. (12), according to Merton's (1973) ICAPM, is the relative risk aversion coefficient which is expected to be positive and statistically significant.

To control for macroeconomic variables and lagged returns that may potentially affect the fluctuations in the FX market, we estimate the risk aversion coefficient, β, after controlling for the federal funds rate, term spread, default spread, and lagged return:

$$R_{t+1} \equiv \alpha + \beta \cdot VAR^{realized}_t + \lambda_1 \cdot FED_t + \lambda_2 \cdot DEF_t + \lambda_3 \cdot TERM_t + \lambda_4 \cdot R_t + \varepsilon_{t+1}, \tag{13}$$

and test the statistical significance of β.

In addition to the GARCH-in-mean and realized volatility models, we use the range-based volatility estimator with and without control variables to test the significance of risk aversion β:

$$R_{t+1} = \alpha + \beta \cdot VAR^{range}_t + \varepsilon_{t+1}, \tag{14}$$

$$R_{t+1} \equiv \alpha + \beta \cdot VAR^{range}_t + \lambda_1 \cdot FED_t + \lambda_2 \cdot DEF_t + \lambda_3 \cdot TERM_t + \lambda_4 \cdot R_t + \varepsilon_{t+1}, \tag{15}$$

where VAR^{range}_t is the Parkinson's (1980) range-based estimator of the daily integrated variance defined in eq. (4).

The uncovered interest rate parity indicates that the appreciation (or depreciation) rate of a currency is related to the interest rate differential of two countries.[8] Therefore, the hedging demand component of the ICAPM is proxied by the short-term interest rates of the two countries. Specifically, the intertemporal relation is tested based on the GARCH-in-mean, realized, and range volatility estimators along with the London Interbank Offer Rate (LIBOR) for the US and the corresponding foreign country:

$$R_{t+1} \equiv \alpha + \beta \cdot \sigma^2_{t+1|t} + \lambda_1 \cdot LIBOR_t^{US} + \lambda_2 \cdot LIBOR_t^{foreign} + \lambda_3 \cdot R_t + \varepsilon_{t+1}, \tag{16}$$

$$R_{t+1} \equiv \alpha + \beta \cdot VAR_t^{realized} + \lambda_1 \cdot LIBOR_t^{US} + \lambda_2 \cdot LIBOR_t^{foreign} + \lambda_3 \cdot R_t + \varepsilon_{t+1}, \tag{17}$$

$$R_{t+1} \equiv \alpha + \beta \cdot VAR_t^{range} + \lambda_1 \cdot LIBOR_t^{US} + \lambda_2 \cdot LIBOR_t^{foreign} + \lambda_3 \cdot R_t + \varepsilon_{t+1}, \tag{18}$$

where $LIBOR_t^{US}$ and $LIBOR_t^{foreign}$ are the LIBOR rates for the US and the corresponding foreign country. To control for a potential first-order serial correlation in daily returns on exchange rates, we include the lagged return (R_t) to the conditional mean specifications.

IV. Empirical Results

Table 4 presents the maximum likelihood parameter estimates and the t-statistics in parentheses for the GARCH-in-mean model. The risk aversion parameter (β) is estimated to be positive for all currencies considered in the paper, but the parameter estimates are not statistically significant, except for the British Pound and the Canadian Dollar. Specifically, β is estimated to be 5.18 for the Euro, 4.42 for the Japanese Yen, 29.07 for the British Pound, 0.87 for the Swiss Franc, 11.04 for the Australian Dollar, and 22.40 for the Canadian Dollar. Based on the Bollerslev-Wooldridge (1992) heteroscedasticity consistent covariance t-statistics reported in Table 4, the risk aversion coefficient has a t-statistic of 1.83 for the Canadian Dollar and t-statistic of 1.77 for the British Pound. Although we do not have a strong statistical significance, we can interpret this finding as a positive risk-return tradeoff in the US/Canadian Dollar and US Dollar/Pound exchange rate markets. Overall, these results indicate a positive, but statistically weak relation between expected return and risk on currency.

Another notable point in Table 4 is the significance of volatility clustering. For all currencies, the conditional volatility parameters (γ_1, γ_2) are positive, between zero and one, and highly significant. The results indicate the presence of rather extreme conditionally heteroskedastic volatility effects in the exchange rate process because the GARCH parameters, γ_1 and γ_2, are found to be not only highly significant, but also the sum ($\gamma_1 + \gamma_2$) is close to one for all exchange rates considered in the paper. This implies the existence of substantial volatility persistence in the FX market.

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[8] Assuming that the interest rate is 5% per annum in the U.S. and 2% per annum in Japan, the uncovered interest rate parity predicts that the U.S. dollar would depreciate against the Japanese Yen by 3%.

Table 5 reports the daily risk aversion parameter estimates and their statistical significance for each currency after controlling for macroeconomic variables and lagged return. The risk-return coefficient estimates are similar to our earlier findings in Table 4. The relationship between expected return and conditional risk is positive but statistically weak for all exchange rates, except for the British Pound and the Canadian Dollar where we have a risk aversion parameter of 36.51 with t-stat. = 1.89 for the British Pound and 27.86 with t-stat. = 2.15 for the Canadian Dollar. These results indicate that controlling for the hedging demand component of the ICAPM does not alter our findings.

Table 5 shows that the slope coefficient (λ_4) on the lagged return is negative for all currencies, but it is statistically significant only for the Euro (with t-stat. = –2.04) and the Swiss Franc (with t-stat. = –2.48).[9] We find a negative but insignificant first-order serial correlation for the Japanese Yen, British Pound, Australian Dollar, and Canadian Dollar.

Table 6 presents the parameter estimates and their Newey-West (1987) adjusted *t*-statistics from the risk-return regressions with daily realized variance. Panel A reports results without the control variables and tests whether the realized variance obtained from the sum of squared 5-minute returns can predict one-day ahead returns on exchange rates. The risk aversion parameter (β) is estimated to be positive for five out of six currencies considered in the paper, but only two of these parameter estimates are statistically significant at the 10% level. Specifically, β is estimated to be 11.39 for the Euro, 7.91 for the Japanese Yen, 7.91 for the British Pound, 13.78 for the Swiss Franc, –1.09 for the Australian Dollar, and 11.89 for the Canadian Dollar. Based on the Newey-West (1987) t-statistics reported in Table 6, the Swiss Franc with a risk aversion parameter of 13.78 (t-stat. = 2.21) and the Euro has a risk aversion coefficient of 11.39 (t-stat. = 1.77). These results indicate that the daily realized variance measure obtained from intraday data positively predict future returns on exchange rates, but the link between risk and return is generally statistically insignificant.

Panel B of Table 6 presents the risk aversion coefficient estimates after controlling for the federal funds rate, term spread, default spread, and lagged return. Similar to our findings in Panel A, the risk aversion parameter is estimated to be 18.76 with t-stat. = 2.42 for the Euro, 8.77 with t-stat. = 1.80 for the Japanese Yen, and 18.89 with t-stat. = 2.70 for the Swiss Franc, indicating a positive and significant link between the realized variance and the one-day ahead returns on the US Dollar/Euro, US Dollar/Yen, and US Dollar/Swiss Franc exchange rates. There is also a positive, but statistically weak relation for the British Pound and the Canadian Dollar.

Table 7 reports the parameter estimates and their Newey-West t-statistics from the risk-return regressions with the daily range variance of Parkinson (1980). As shown in both panels, with and without

[9] Jegadeesh (1990), Lehmann (1990), and Lo and MacKinlay (1990) provide evidence for the significance of short-term reversal (or negative autocorrelation) in short-term stock returns.

control variables, the risk aversion parameter (β) is estimated to be positive but statistically insignificant, except for the marginal significance of β for the Canadian dollar in Panel B. These results provide evidence that the daily range volatility obtained from the intraday data positively predict future returns on exchange rates, but there is no significant relation between risk and return on currency.

The estimates in Tables 6 and 7 present a negative and significant autocorrelation for the Euro, Japanese Yen, Swiss Franc, and Canadian Dollar. The first-order autocorrelation coefficient is negative, but statistically insignificant for the British Pound and the Australian Dollar.

An interesting observation in Tables 5, 6, and 7 is that the slope coefficients (λ_1, λ_2, λ_3) on the lagged macroeconomic variables are found to be statistically insignificant, except for some marginal significance for the term spread in the regressions with the Swiss Franc. Although one would think that unexpected news in macroeconomic variables could be viewed as risks that would be rewarded in the FX market, we find that the changes in federal funds rate, term and default spreads do not affect time-series variation in daily exchange rate returns. Our interpretation is that it would be very difficult for macroeconomic variables to explain daily variations in exchange rates. If we examined the risk-return tradeoff at lower frequency (such as monthly or quarterly frequency), we might observe significant impact of macroeconomics variables on monthly or quarterly variations in exchange rates.

Panel A of Table 8 presents the maximum likelihood parameter estimates and the t-statistics in parentheses for the GARCH-in-mean model with LIBOR rates for the US and the corresponding foreign country. The risk aversion parameter (β) is estimated to be positive for all currencies, but the parameter estimates are statistically significant only for the British Pound, Australian Dollar, and Canadian Dollar. Specifically, β is estimated to be 30.87 for the British Pound, 17.75 for the Australian dollar, and 32.90 for the Canadian Dollar. Based on the Bollerslev-Wooldridge heteroscedasticity consistent covariance t-statistics reported in Table 8, the risk aversion coefficient has a t-statistic of 1.82 for the British Pound, 1.84 for the Australian Dollar, and 2.36 for the Canadian Dollar. Although we do not have a strong statistical significance, we can interpret this finding as a positive risk-return tradeoff in the US Dollar/British Pound, US/Australian Dollar, and US/Canadian dollar markets. Overall, the results indicate a positive, but statistically weak relation between expected return and risk on currency.

Another point worth mentioning in Panel A is that the slope coefficients on the US LIBOR rate are estimated to be positive and statistically significant at the 5% level for the Euro, Japanese Yen, and Swiss Franc and significant at the 10% level for the Canadian Dollar. As expected, the slope coefficients on the LIBOR rates of the corresponding foreign country turn out to be negative, but statistically insignificant.

Panel B of Table 8 reports the parameter estimates and their Newey-West adjusted t-statistics from the risk-return regressions with daily realized variance after controlling for the LIBOR rates and the lagged return. The results indicate a positive and significant link between the realized variance and the one-day ahead returns on the Euro, Japanese Yen, Swiss Franc, and Canadian Dollar. There is also a positive, but statistically weak relation for the British Pound.

Panel C of Table 8 shows the parameter estimates and their Newey-West t-statistics from the risk-return regressions with the daily range variance of Parkinson (1980). With LIBOR rates and the lagged return, the risk aversion parameter (β) is estimated to be positive for all currencies, but statistically significant only for the Canadian Dollar. Overall, the results provide evidence that after controlling for the interest rate differential of two countries, there is a positive but statistically weak relation between risk and return on currency.

Similar to our earlier findings from the GARCH-in-mean model, Panels B and C of Table 8 show that the slope coefficients on the US LIBOR rate are generally positive, whereas the slopes on the corresponding foreign LIBOR rates are negative with a few exceptions.

Many studies fail to identify a statistically significant intertemporal relation between risk and return of the stock market portfolios. French, Schwert, and Stambaugh (1987) find that the coefficient estimate is not significantly different from zero when they use past daily returns to estimate the monthly conditional variance.[10] Chan, Karolyi, and Stulz (1992) employ a bivariate GARCH-in-mean model to estimate the conditional variance, and they also fail to obtain a significant coefficient estimate for the United States. Campbell and Hentchel (1992) use the quadratic GARCH (QGARCH) model of Sentana (1995) to determine the existence of a risk-return tradeoff within an asymmetric GARCH-in-mean framework. Their estimate is positive for one sample period and negative for another sample period, but neither is statistically significant. Glosten, Jagannathan, and Runkle (1993) use monthly data and find a negative but statistically insignificant relation from two asymmetric GARCH-in-mean models. Based on semi-nonparametric density estimation and Monte Carlo integration, Harrison and Zhang (1999) find a significantly positive risk and return relation at one-year horizon, but they do not find a significant relation at shorter holding periods such as one month. Using a sample of monthly returns and implied and realized volatilities for the S&P 500 index, Bollerslev and Zhou (2006) find an insignificant intertemporal relation between expected return and realized volatility, whereas the relation between return and implied volatility turns out to be significantly positive.

Several studies find that the intertemporal relation between risk and return is negative (e.g., Campbell (1987), Breen, Glosten, and Jagannathan (1989), Turner, Startz, and Nelson (1989), Nelson (1991), Glosten, Jagannathan, and Runkle (1993), Harvey (2001), and Brandt and Kang (2004)). Some studies do provide evidence supporting a positive and significant relation between expected return and

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[10] When testing monthly risk-return tradeoff, French, Schwert, and Stambaugh (1987) use the monthly realized variance obtained from the sum of squared daily returns within a month.

risk on stock market portfolios (e.g., Bollerslev, Engle, and Wooldridge (1988), Scruggs (1998), Ghysels, Santa-Clara, and Valkanov (2005), Bali and Peng (2006), Guo and Whitelaw (2006), Lundblad (2007), and Bali (2008)).

Merton's (1973) ICAPM provides a theoretical model that gives a positive equilibrium relation between the conditional first and second moments of excess returns on the aggregate market portfolio. However, Abel (1988), Backus and Gregory (1993), and Gennotte and Marsh (1993) develop models in which a negative relation between expected return and volatility is consistent with equilibrium. As summarized above, there has been a lively debate on the existence and direction of a risk-return tradeoff and empirical studies are still not in agreement for the stock market portfolios. The empirical results presented in Tables 4-8 indicate that the intertemporal relation between expected return and risk on currency is positive, but in most cases statistically insignificant. Hence, our findings from the FX market are in line with some of the earlier studies that investigated the significance of a risk-return tradeoff for the stock market.

V. Time-Varying Risk Aversion in the Foreign Exchange Market

Chou, Engle and Kane (1992), Harvey (2001), and Lettau and Ludvigson (2004) suggest that the risk-return relation for the stock market may be time-varying. In the existing literature, there is no study investigating the presence and significance of time-varying risk aversion in the FX market. We have so far assumed a constant risk-return tradeoff in currency markets and found a positive but statistically insignificant relation between expected return and risk on exchange rates.

We now estimate the dependence of expected returns on the lagged realized variance over time using rolling regressions. This also allows us to check whether our results are driven by a particular sample period. We estimate the risk-return relation specified in equations (12) and (13) for the six exchange rates with rolling samples. We used two different rolling regression approaches. The first one uses a fixed rolling window of 250 business days (i.e., approximately 1 year), whereas the second one starts with the in-sample period of 250 business days and then extends the sample by adding each daily observation to the estimation while keeping the start date constant.

Figure 1 plots the estimated relative risk aversion parameters (β) and their statistical significance over time from the fixed rolling window of 250 days.[11] Specifically, the first 250 daily return observations of exchange rates and their realized variances (from 1/3/2002 to 1/8/2003) are used for estimation of the relative risk aversion parameter for 1/8/2003. The sample is then rolled forward by removing the first

[11] Since the time-varying risk aversion coefficients from estimating equations (12) and (13) with and without control variables turn out to be very similar, we only report results from the full specification of eq. (13). Time-varying risk aversion estimates obtained from the parsimonious specification of eq. (12) are available from the authors upon request.

observation of the sample and adding one to the end, and another one-day ahead risk-return relationship is measured. This recursive estimation procedure is repeated until the sample is exhausted on March 31, 2008. The estimated relative risk aversion parameter over the fixed rolling sample period represents the average degree of risk aversion over that sample period. Computation of the relative risk aversion parameters using a rolling window of data allows us to observe the time variation in investors' average risk aversion.

A common observation in Figure 1 is that there is a strong time-series variation in the risk aversion estimates for all currencies considered in the paper. The first panel in Figure 1 indicates that in the US dollar/Euro FX market, the aggregate risk aversion is generally positive with some exceptions in the second half of 2006 and from May to August 2007. For the out-of-sample period of January 2003 to March 2008, only 208 out of 1,306 daily risk aversion estimates are negative. Based on the Newey-West adjusted t-statistics, all of these negative risk aversion estimates are statistically insignificant. 143 (291) out of 1,098 positive risk aversion estimates turn out to be statistically significant at least at the 5% level (10% level). These results indicate a positive but statistically insignificant time-varying risk aversion in the US dollar/Euro market.

The second panel in Figure 1 displays that in the Japanese Yen market, the aggregate risk aversion is generally positive but there are quite a lot of days in which we observe a negative relation between expected return and risk in the US dollar/Yen market. 431 out of 1,306 daily risk aversion estimates are negative, but about one-third is statistically significant at the 10% level. 185 (314) out of 875 positive risk aversion estimates turn out to be statistically significant at least at the 5% level (10% level). These results indicate that there is a positive but not strong time-varying risk aversion in the US Dollar/Yen exchange rate market.

Third panel in Figure 1 shows that in the US Dollar/Pound Sterling market, the risk aversion is generally positive but there is a long period of time in which we observe a negative relation between expected return and risk in the US dollar/Pound market. Specifically, 872 out of 1,306 daily risk aversion estimates are positive, but only 5 out of 872 are marginally significant. Similarly, only 46 out of 434 negative risk aversion estimates turn out to be statistically significant at the 10% level. These results provide evidence that although there is a significant time-variation in the aggregate risk aversion, it is not clear whether the currency trade generates a larger or smaller risk premium at times when the US dollar/Pound FX market is riskier.

The fourth panel in Figure 1 indicates that in the Swiss Franc market, the risk aversion is estimated to be positive throughout the sample period (2002-2008), except for a few months in 2006. Only 71 out of 1,306 daily risk aversion estimates are negative, but none of them is statistically significant. 353 (467) out of 1,235 positive risk aversion estimates turn out to be statistically significant at least at the 5% level (10% level). These results indicate a positive and relatively strong time-varying risk aversion, implying that the currency trade generates a larger risk premium at times when the US Dollar/Swiss Franc trade becomes riskier.

The fifth panel in Figure 1 indicates that in the Australian dollar market 736 out of 1,306 daily risk aversion estimates are positive, but none of them is statistically significant. Only 65 out of 570 negative risk aversion estimates turn out to be marginally significant at the 10% level. The figure indicates a strong time-varying risk aversion, but there is no significantly positive or negative relation between risk and return in the US/Australian Dollar exchange rate market.

The last panel in Figure 1 demonstrates that in the US/Canadian Dollar market, for slightly more than half of the sample, the risk aversion is estimated to be positive and slightly less than half of the sample it turns out to be negative. However, based on the t-statistics of these risk aversion estimates, there is no evidence for a significantly positive or negative link between expected return and risk on currency. Only 35 out of 757 positive risk aversion coefficients and only 46 out of 549 negative risk aversion parameters are found to be significant at the 10% level. Although there is a significant time-series variation in the aggregate risk aversion, trading in the US/Canadian Dollar FX market does not provide clear evidence for a larger or smaller risk premium at times when the market is riskier.

Figure 2 plots the estimated relative risk aversion parameters (β) and their statistical significance over time from the rolling regressions with a fixed starting date. Specifically, the first 250 daily return observations of exchange rates and their realized variances (from 1/3/2002 to 1/7/2003) are used for estimation of the relative risk aversion parameter for 1/8/2003. The sample is then extended by adding one observation to the end (from 1/3/2002 to 1/8/2003), and the one-day ahead risk-return relation is measured for 1/9/2003. This recursive estimation procedure is repeated until March 31, 2008.

Similar to our findings from the fixed rolling window regressions, Figure 2 provides evidence for a significant time-variation in the risk aversion estimates for all currencies considered in the paper. The first panel in Figure 2 shows that in the US Dollar/Euro market, the aggregate risk aversion is positive with a few exceptions in January 2003. Only 16 out of 1,306 risk aversion estimates are negative but none of these estimates is statistically significant based on the Newey-West t-statistics. 795 (870) out of 1,290 positive risk aversion estimates turn out to be statistically significant at least at the 5% level (10% level). These results indicate a positive and strong time-varying risk aversion in the US Dollar/Euro market.

The second panel in Figure 2 shows that in the US Dollar/Yen FX market, the aggregate risk aversion is positive with a few exceptions from March to June 2004. Only 68 out of 1,306 risk aversion estimates are negative and all of them are statistically insignificant. 129 out of 1,238 positive risk aversion estimates turn out to be marginally significant at the 10% level. These results imply a positive but statistically weak time-varying risk aversion in the US Dollar/Yen market.

The third panel in Figure 2 depicts that in the Pound Sterling market, the risk aversion is positive throughout the sample, except for a short period of time in 2003. Only 90 out of 1,306 risk aversion estimates are negative, but they are not statistically significant. Although there is a significant time-variation in the risk aversion and most of the risk-return coefficients is positive, only 41 out of 1,216 positive risk aversion estimates turn out to be significant at the 10% level. Therefore, it is not clear whether the currency trade generates a larger or smaller risk premium at times when the US Dollar/Pound market is riskier.

The fourth panel in Figure 2 provides evidence that in the Swiss Franc market, the risk aversion is estimated to be positive throughout the sample period (2002-2008), except for a few days in January 2003. Only 20 out of 1,306 risk aversion estimates are negative but statistically insignificant. 816 (934) out of 1,286 positive risk aversion estimates turn out to be statistically significant at least at the 5% level (10% level). These results suggest a positive and strong time-varying risk aversion, implying that the currency trade generates a larger risk premium at times when the US Dollar/Swiss Franc exchange rate market is riskier.

The fifth panel in Figure 2 shows that in the Australian Dollar market only 138 out of 1,306 risk aversion estimates are negative with no statistical significance even at the 10% level. Only 106 out of 1,168 positive risk aversion coefficients are found to be marginally significant at the 10% level. Although there is significant time-variation in the aggregate risk aversion, the results do not suggest a strong positive or negative link between expected return and risk in the US/Australian Dollar market.

The last panel in Figure 2 demonstrates that in the US/Canadian Dollar market, the risk aversion is estimated to be positive, except for a few days in May, October, and November 2003. Similar to our earlier findings, only 41 out of 1,308 risk aversion estimates are negative with very low t-statistics. However, based on the statistical significance of positive risk aversion estimates, there is no evidence for a strong positive link between expected return and risk on currency either. Only 276 out of 1,265 positive risk aversion coefficients are found to be significant at the 10% level. Although there is a significant time-series variation in the aggregate risk aversion, trading in the US/ Canadian Dollar FX market does not provide clear evidence for a larger or smaller risk premium at times when the market is riskier.

VI. Testing Merton's (1973) ICAPM in Currency Market

Merton's (1973) ICAPM implies the following equilibrium relation between risk and return for any risky asset *i*:

$$\mu_i - r = A \cdot \sigma_{im} + B \cdot \sigma_{ix}, \tag{19}$$

where *r* is the risk-free interest rate, $\mu_i - r$ is the expected excess return on the risky asset *i*, σ_{im} denotes the covariance between the returns on the risky asset *i* and the market portfolio *m*, and σ_{ix} denotes a

($1 \times k$) row of covariances between the returns on risky asset i and the k state variables x. A denotes the average relative risk aversion of market investors, and B measures the market's aggregate reaction to shifts in a k-dimensional state vector that governs the stochastic investment opportunity. Equation (19) states that in equilibrium, investors are compensated in terms of expected return for bearing market risk and for bearing the risk of unfavorable shifts in the investment opportunity set.

Merton (1980) shows that the intertemporal hedging demand component ($B \cdot \sigma_{ix}$) is economically and statistically smaller than the market risk component ($A \cdot \sigma_{im}$) of ICAPM. While testing the significance of A and B at daily frequency, Bali and Engle (2007) provide supporting evidence for Merton (1980) that the conditional covariances of individual stocks with the market portfolio have positive and statistically significant loading, whereas the innovations in state variables are not priced in the stock market. That is, the conditional covariances of stock returns with the unexpected news in state variables have insignificant loadings.

We examine Merton's (1973) ICAPM based on the following system of equations:

$$\begin{aligned} R_{i,t+1} &= C_i + A \cdot \sigma_{im,t} + \varepsilon_{i,t+1}, \\ R_{m,t+1} &= C_m + A \cdot \sigma^2_{m,t} + \varepsilon_{m,t+1}, \end{aligned} \tag{20}$$

where the expected conditional covariance of individual exchange rates with the currency market, $E_t(\sigma_{im,t+1})$, is represented by the one-day lagged realized covariance, i.e., $E_t(\sigma_{im,t+1}) = \sigma_{im,t}$. Similarly, the expected conditional variance of the currency market, $E_t(\sigma^2_{m,t+1})$, is represented by the one-day lagged realized variance, i.e., $E_t(\sigma^2_{m,t+1}) = \sigma^2_{m,t}$.[12]

The currency market portfolio is measured by the "value-weighted" average returns on EUR, JPY, GBP, CHF, AUD, and CAD. The weights are obtained from the "US Dollar Index". Just as the Dow Jones Industrial Average reflects the general state of the US stock market, the US Dollar Index (USDX) reflects the general assessment of the US Dollar. USDX does it through exchange rates averaging of US Dollar and six most tradable global currencies. The weights are 57.6% for EUR, 13.6% for JPY, 11.9% for GBP, 9.1% CAD, 4.2% for AUD, and 3.6% for CHF. In our empirical analysis, daily returns on the currency market, $R_{m,t+1}$, are calculated by multiplying daily returns on the six exchange rates by the aforementioned weights.

We estimate the system of equations (20) using an ordinary least square (OLS) as well as a weighted least square method that allows us to place constraints on coefficients across equations. We

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[12] Daily realized covariances between the exchange rates and the currency market and daily realized variance of the currency market are computed using five-minute returns in a day.

constrain the slope coefficient (A) on the lagged realized variance-covariance matrix ($\sigma_{im,t}, \sigma^2_{m,t}$) to the same value across all the currencies for cross-sectional consistency. We allow the intercepts (C_i, C_m) to differ across all the currencies. Under the null hypothesis of the ICAPM, the intercepts should be jointly zero and the common slope coefficient (A) should be positive and statistically significant. We use insignificant estimates of A and the deviations from zero of the intercept estimates as a test against the validity and sufficiency of the ICAPM. In addition to the OLS panel estimates, we compute the t-statistics of the parameter estimates accounting for heteroskedasticity and autocorrelation as well as contemporaneous cross-correlations in the error terms. This estimation methodology for the system of equations (20) can be regarded as an extension of the seemingly unrelated regression (SUR) method.

Table 9 presents the OLS and SUR panel regression estimates of the currency-specific intercepts, common slope coefficients on the lagged realized variance-covariance matrix, and their t-statistics. The parameters and their t-statistics are estimated using the daily returns on the currency market and the six exchange rates. The last row reports the Wald statistics with p-values from testing the joint hypothesis that all intercepts equal zero: $H_0 : C_1 = C_2 = ... = C_6 = C_m = 0$. A notable point in Table 9 is that the common slope coefficient (A) is positive and statistically significant. Specifically, the risk aversion coefficient on the realized variance-covariance matrix is estimated to be 23.33 with a t-statistic of 5.40. After correcting for heteroscedasticity, autocorrelation, and contemporaneous cross-correlations, the SUR estimate of the risk aversion coefficient turns out to be 15.80 with t-stat. = 2.57. These results indicate a positive and significant relation between risk and return on the currency market. Another notable point in Table 9 is that for both the OLS and SUR estimates, the Wald statistics reject the hypothesis that all intercepts equal zero. This implies that the market risk alone cannot explain the entire time-series variation in exchange rates.

According to the original ICAPM of Merton (1973), the relative risk aversion coefficient (A) is restricted to the same value across all risky assets and it is positive and statistically significant. The common slope estimates in Table 9 provide empirical support for the positive risk-return tradeoff.

We now test whether the slopes on (σ_{im}, σ^2_m) are different across currencies. We examine the sign and statistical significance of different slope coefficients (A_i, A_m) on (σ_{im}, σ^2_m) in the following system of equations:

$$R_{i,t+1} = C_i + A_i \cdot \sigma_{im,t} + \varepsilon_{i,t+1}, \qquad (21)$$
$$R_{m,t+1} = C_m + A_m \cdot \sigma^2_{m,t} + \varepsilon_{m,t+1},$$

To determine whether there is a common slope coefficient (A) that corresponds to the average relative risk aversion, we first estimate the currency-specific slope coefficients (A_i, A_m) and then test the joint hypothesis that $H_0 : A_1 = A_2 = ... = A_6 = A_m$.

Table 10 presents the OLS and SUR parameter estimates using daily returns on the six exchange rates and the value-weighted currency market index. As compared to equation (20), we have an additional six slope coefficients to estimate in equation (21). As shown in Table 10, all of the slope coefficients (A_i, A_m) are estimated to be positive and highly significant without any exception. These results indicate a positive and significant intertemporal relation between risk and return on the currency market. We examine the cross-sectional consistency of the intertemporal relation by testing the equality of slope coefficients based on the Wald statistic. As reported in Table 10, the Wald statistic from testing the joint hypothesis that $H_0 : A_1 = A_2 = ... = A_6 = A_m$ is 1.41 for OLS and 5.24 for SUR, which fail to reject the null hypothesis. These results indicate the equality of positive slope coefficients across all currencies, which empirically validates the ICAPM.

VII. Conclusion

There is an ongoing debate in the literature about the intertemporal relation between stock market risk and return and the extent to which expected stock returns are related to expected market volatility. Recently, some studies have provided evidence for a significantly positive link between risk and return in the aggregate stock market, but the risk-return tradeoff is generally found to be insignificant and sometimes even negative. This paper is the first to investigate the presence and significance of an intertemporal relation between expected return and risk in the foreign exchange market. The paper provides new evidence on the ICAPM by using high-frequency intraday data on currency and by presenting significant time-variation in the risk aversion parameter. We utilize daily and 5-minute returns on the spot exchange rates of the U.S. dollar vis-à-vis six major currencies (the Euro, Japanese Yen, British Pound Sterling, Swiss Franc, Australian Dollar, and Canadian Dollar) and test the existence and significance of a risk-return tradeoff in the FX market using the GARCH, realized, and range-based volatility measures. The maximum likelihood parameter estimates of the GARCH-in-mean model and the risk-return regressions with daily realized and range volatility estimators indicate that the intertemporal relation between risk and return is generally positive but statistically weak in the FX market.

We provide strong evidence on the time-variation of risk aversion parameters for all currencies considered in the paper. However, the direction of a relationship between expected return and risk is not clear. The results indicate a positive but not strong time-varying risk aversion in the US Dollar/Euro exchange rate market. The risk-return regressions with realized variance provide evidence for a positive but statistically weak risk aversion estimates in the US Dollar/Yen market. Although there is a significant time-variation in risk-aversion estimates for the British Pound, it is not clear whether the currency trade generates a larger or smaller risk premium at times when the US Dollar/Pound market is riskier. The risk aversion parameter is estimated to be positive but marginally significant throughout the sample period for the Swiss Franc, implying that the currency trade generally yields a larger risk premium at times when the US Dollar/Swiss Franc market is riskier. For most of the sample, the risk-return coefficients are estimated to be positive but statistically insignificant for the Canadian dollar, suggesting that the intertemporal relation between risk and return is flat for the US/Canadian Dollar market.

Table 1. Reported foreign exchange market turnover by currency pair*
(Daily averages in April, in billions of US dollars and per cent)

	2001		2004		2007	
	Amount	**% share**	**Amount**	**% share**	**Amount**	**% share**
US dollar/euro	354	30	503	28	840	27
US dollar/yen	231	20	298	17	397	13
US dollar/British pound	125	11	248	14	361	12
US dollar/Australian dollar	47	4	98	5	175	6
US dollar/Swiss franc	57	5	78	4	143	5
US dollar/Canadian dollar	50	4	71	4	115	4
US dollar/other	195	17	295	16	628	21
Euro/yen	30	3	51	3	70	2
Euro/sterling	24	2	43	2	64	2
Euro/Swiss franc	12	1	26	1	54	2
Euro/other	21	2	39	2	112	4
Other currency pairs	26	2	42	2	122	4
All currency pairs	1,173	100	1,794	100	3,081	100

* Adjusted for local and cross-border double-counting.

Table 2. Most traded currencies –
Currency distribution of reported FX market turnover

Currency	**Symbol**	**% daily share**
US dollar	USD ($)	88.7%
Euro	EUR (€)	37.2%
Japanese yen	JPY (¥)	20.3%
British pound sterling	GBP (£)	16.9%
Swiss franc	CHF (Fr)	6.1%
Australian dollar	AUD ($)	5.5%
Canadian dollar	CAD ($)	4.2%
Swedish krona	SEK (kr)	2.3%
Hong Kong dollar	HKD ($)	1.9%
Norwegian krone	NOK (kr)	1.4%
Other		15.5%
Total		200%

Table 3. Descriptive Statistics

This table reports statistics for daily returns on US Dollar exchange rates (Panel A), daily realized variance (Panel B), and daily range variance (Panel C) for six major currencies: the Euro (EUR), Japanese Yen (JPY), British Pound Sterling (GBP), Swiss Franc (CHF), Australian Dollar (AUD), and Canadian Dollar (CAD). Mean, median, maximum, minimum, standard deviation, skewness, kurtosis, and AR(1) statistics are reported for each currency. Standard errors of skewness and kurtosis estimates, computed under the null hypothesis that the returns are normally distributed, are $\sqrt{6/n}$ and $\sqrt{24/n}$, respectively. Jarque-Bera, JB = $n[(S^2/6) + (K–3)^2/24]$, is a formal statistic for testing whether the returns are normally distributed, where n denotes the number of observations, S is skewness and K is kurtosis. The JB statistic distributed as the Chi-square with two degrees of freedom measures the difference of the skewness and kurtosis of the series with those from the normal distribution. The sample period is from January 3, 2002 to March 31, 2008, yielding a total of 1,556 daily observations. *,** denote statistical significance at the 5% and 1% level, respectively.

Panel A. Descriptive Statistics for the Daily Returns on Exchange Rates

	EUR	JPY	GBP	CHF	AUD	CAD
Mean	–0.00033	–0.000076	–0.00020	–0.00029	–0.00034	–0.00025
Median	–0.00024	0.00004	–0.00029	–0.00012	–0.00064	–0.00032
Maximum	0.01963	0.02515	0.01756	0.02126	0.03496	0.02563
Minimum	–0.01837	–0.02686	–0.02048	–0.02223	–0.02259	–0.01734
Std. Dev.	0.00563	0.00580	0.00504	0.00635	0.00681	0.00520
Skewness	0.0783	–0.1522**	0.0776	–0.0306	0.5377**	0.1091
Kurtosis	3.6142**	4.2687**	3.4508**	3.5184**	4.5571**	3.8636**
Jarque-Bera	26.05**	110.36**	14.74**	17.67**	232.18**	51.44**
AR(1)	–0.0643**	–0.0504*	–0.0117	–0.0788**	0.0164	–0.0642**

Panel B. Descriptive Statistics for the Daily Realized Variance Measures

	EUR	JPY	GBP	CHF	AUD	CAD
Mean	3.47×10^{-5}	4.07×10^{-5}	2.77×10^{-5}	4.31×10^{-5}	6.00×10^{-5}	3.60×10^{-5}
Median	3.13×10^{-5}	3.39×10^{-5}	2.50×10^{-5}	3.77×10^{-5}	4.86×10^{-5}	3.09×10^{-5}
Maximum	0.000253	0.000505	0.000156	0.000367	0.000904	0.00022
Minimum	6.51×10^{-6}	4.05×10^{-6}	5.42×10^{-6}	7.54×10^{-6}	1.48×10^{-5}	5.12×10^{-6}
Std. Dev.	1.93×10^{-5}	3.12×10^{-5}	1.37×10^{-5}	2.48×10^{-5}	4.39×10^{-5}	2.30×10^{-5}
Skewness	2.5435**	6.2585**	2.2476**	3.1791**	6.8653**	2.5195**
Kurtosis	19.957**	71.480**	13.655**	28.010**	104.839**	13.591**
Jarque-Bera	20319.0**	314192.0**	8670.8**	43174.2**	684614.4**	8918.8**
AR(1)	0.50**	0.55**	0.51**	0.49**	0.62**	0.64**

Panel C. Descriptive Statistics for the Daily Range Variance Measures

	EUR	JPY	GBP	CHF	AUD	CAD
Mean	2.76×10^{-5}	3.15×10^{-5}	2.30×10^{-5}	3.56×10^{-5}	4.20×10^{-5}	2.63×10^{-5}
Median	1.91×10^{-5}	2.14×10^{-5}	1.61×10^{-5}	2.52×10^{-5}	2.68×10^{-5}	1.83×10^{-5}
Maximum	0.000204	0.000558	0.000189	0.000364	0.000777	0.000297
Minimum	1.37×10^{-6}	3.58×10^{-7}	1.46×10^{-6}	1.55×10^{-6}	2.58×10^{-6}	1.66×10^{-6}
Std. Dev.	2.62×10^{-5}	3.69×10^{-5}	2.09×10^{-5}	3.41×10^{-5}	5.20×10^{-5}	2.70×10^{-5}
Skewness	2.2886**	5.2166**	2.3097**	2.5960**	5.4669**	3.3357**
Kurtosis	9.953**	50.502**	11.119**	13.832**	51.593**	22.051**
Jarque-Bera	4492.6**	153348.5**	5657.0**	9354.9**	160839.7**	26417.1**
AR(1)	0.09**	0.25**	0.19**	0.12*	0.34**	0.28**

Table 4. Daily Risk-Return Tradeoff in Foreign Exchange Markets Based on the GARCH-in-mean Model

The following GARCH-in-mean process is used with conditional normal density to model the intertemporal relation between expected return and risk on currency:

$$R_{t+1} \equiv \alpha + \beta \cdot \sigma^2_{t+1|t} + \varepsilon_{t+1}$$
$$\varepsilon_{t+1} = z_{t+1} \cdot \sigma_{t+1|t}, \quad z_{t+1} \sim N(0,1), \quad E(\varepsilon_{t+1}) = 0$$
$$E(\varepsilon^2_{t+1} \,|\, \Omega_t) = \sigma^2_{t+1|t} = \gamma_0 + \gamma_1 \varepsilon^2_t + \gamma_2 \sigma^2_t$$

where R_{t+1} is the daily return on exchange rates for period t+1, $\mu_{t+1|t} \equiv \alpha + \beta \cdot \sigma^2_{t+1|t}$ is the conditional mean for period t+1 based on the information set up to time t denoted by Ω_t, $\varepsilon_{t+1} = z_{t+1} \cdot \sigma_{t+1|t}$ is the error term with $E(\varepsilon_{t+1}) = 0$, $\sigma_{t+1|t}$ is the conditional standard deviation of daily returns on currency and $z_{t+1} \sim N(0,1)$ is a random variable drawn from the standard normal density and can be viewed as information shocks in FX markets. $\sigma^2_{t+1|t}$ is the conditional variance of daily returns based on the information set up to time t denoted by Ω_t. The conditional variance, $\sigma^2_{t+1|t}$, follows a GARCH(1,1) process defined as a function of the last period's unexpected news (or information shocks), z_t, and the last period's variance, σ^2_t. The table presents the maximum likelihood parameter estimates and the t-statistics in parentheses.

Parameters	EUR	JPY	GBP	CHF	AUD	CAD
α	–0.0005	–0.0002	–0.0009	–0.0003	–0.0008	–0.0008
	(–1.46)	(–0.30)	(–2.25)	(–0.72)	(–2.26)	(–2.70)
β	5.1772	4.4206	29.065	0.8693	11.042	22.399
	(0.47)	(0.28)	(1.77)	(0.08)	(1.28)	(1.83)
γ_0	1.09×10^{-7}	1.69×10^{-6}	3.37×10^{-7}	2.60×10^{-7}	6.97×10^{-7}	2.45×10^{-7}
	(0.65)	(1.76)	(2.32)	(1.00)	(0.92)	(2.21)
γ_1	0.0301	0.0587	0.0430	0.0331	0.0541	0.0420
	(4.25)	(4.57)	(4.51)	(4.24)	(3.81)	(4.82)
γ_2	0.9672	0.8922	0.9443	0.9617	0.9318	0.9502
	(116.10)	(35.85)	(73.13)	(107.35)	(50.04)	(93.08)

Table 5. Daily Risk-Return Tradeoff in Foreign Exchange Markets Based on the GARCH-in-mean Model with Control Variables

The following GARCH-in-mean process is used with control variables to estimate the intertemporal relation between expected return and risk on currency:

$$R_{t+1} \equiv \alpha + \beta \cdot \sigma^2_{t+1|t} + \lambda_1 \cdot FED_t + \lambda_2 \cdot DEF_t + \lambda_3 \cdot TERM_t + \lambda_4 \cdot R_t + \varepsilon_{t+1}$$
$$\varepsilon_{t+1} = z_{t+1} \cdot \sigma_{t+1|t}, \quad z_{t+1} \sim N(0,1), \quad E(\varepsilon_{t+1}) = 0$$
$$E(\varepsilon^2_{t+1} \mid \Omega_t) = \sigma^2_{t+1|t} = \gamma_0 + \gamma_1 \varepsilon^2_t + \gamma_2 \sigma^2_t$$

where FED_t, DEF_t, and $TERM_t$ are macroeconomic variables that proxy for the hedging demand component of ICAPM, and R_t is the lagged daily return. The federal funds rate (*FED*) is the interest rate at which a depository institution lends immediately available funds (balances at the Federal Reserve) to another depository institution overnight. The term spread (*TERM*) is calculated as the difference between the yields on the 10-year Treasury bond and the 3-month Treasury bill. The default spread (*DEF*) is computed as the difference between the yields on the BAA-rated and AAA-rated corporate bonds. The table presents the maximum likelihood parameter estimates and the t-statistics in parentheses.

Parameters	EUR	JPY	GBP	CHF	AUD	CAD
α	–0.0003	0.0024	–0.0012	0.0006	0.0007	–0.0013
	(–0.13)	(1.54)	(–0.73)	(0.29)	(0.39)	(–0.95)
β	6.9731	15.986	36.514	17.913	16.478	29.329
	(0.68)	(0.96)	(1.89)	(1.17)	(1.56)	(2.15)
λ_1	-2.19×10^{-4}	-3.76×10^{-4}	-1.00×10^{-4}	-2.43×10^{-4}	-3.11×10^{-4}	-4.64×10^{-5}
	(–0.66)	(–1.13)	(–0.35)	(–0.69)	(–0.90)	(–0.18)
λ_2	5.58×10^{-5}	-7.24×10^{-4}	8.06×10^{-4}	1.00×10^{-4}	8.66×10^{-5}	7.33×10^{-4}
	(0.07)	(–0.96)	(1.13)	(0.09)	(0.10)	(1.03)
λ_3	-5.33×10^{-4}	-6.79×10^{-4}	-2.71×10^{-4}	-5.82×10^{-4}	-5.64×10^{-4}	-1.62×10^{-4}
	(–1.45)	(–1.65)	(–0.82)	(–1.43)	(– 1.27)	(–0.50)
λ_4	–0.055	–0.042	–0.008	–0.062	–0.010	–0.038
	(–2.04)	(–1.48)	(–0.30)	(–2.48)	(–0.35)	(–1.45)
γ_0	1.14×10^{-7}	1.64×10^{-6}	3.13×10^{-7}	2.37×10^{-7}	7.32×10^{-7}	2.42×10^{-7}
	(0.99)	(2.94)	(2.30)	(1.83)	(2.63)	(2.15)
γ_1	0.0311	0.0581	0.0408	0.0331	0.0566	0.0417
	(4.56)	(4.41)	(4.52)	(3.81)	(4.03)	(4.80)
γ_2	0.9660	0.8938	0.9475	0.9622	0.9285	0.9506
	(97.28)	(33.74)	(77.76)	(88.65)	(53.11)	(92.60)

Table 6. Daily Risk-Return Tradeoff in Foreign Exchange Markets Based on the Realized Variance

The following regression is estimated with and without control variables to test the significance of the intertemporal relation between expected return and risk on currency:

$$R_{t+1} \equiv \alpha + \beta \cdot VAR_t^{realized} + \lambda_1 \cdot FED_t + \lambda_2 \cdot DEF_t + \lambda_3 \cdot TERM_t + \lambda_4 \cdot R_t + \varepsilon_{t+1}$$

where $VAR_t^{realized}$ is the daily realized variance computed as the sum of squared 5-minute returns on exchange rates. The table presents the parameter estimates and their Newey-West (1987) t-statistics in parentheses.

Panel A. Daily Risk-Return Tradeoff without Control Variables

Parameters	EUR	JPY	GBP	CHF	AUD	CAD
α	–0.00073	–0.00040	–0.00042	–0.00088	–0.00027	–0.00068
	(–2.84)	(–1.59)	(–1.77)	(–2.90)	(–0.77)	(–2.25)
β	11.393	7.9064	7.9145	13.777	–1.0895	11.885
	(1.77)	(1.61)	(1.07)	(2.21)	(–0.21)	(1.38)

Panel B. Daily Risk-Return Tradeoff with Control Variables

Parameters	EUR	JPY	GBP	CHF	AUD	CAD
α	0.00124	0.00257	0.00080	0.00169	0.00030	–0.00074
	(0.82)	(1.58)	(0.57)	(0.96)	(0.17)	(–0.49)
β	18.759	8.7656	10.429	18.886	–0.0858	13.608
	(2.42)	(1.80)	(1.30)	(2.70)	(–0.01)	(1.55)
λ_1	–0.00028	–0.00035	–0.00025	–0.00033	4.4×10^{-6}	–0.00007
	(–0.99)	(–1.06)	(–0.90)	(–1.03)	(0.01)	(–0.25)
λ_2	–0.00051	–0.00112	0.00013	–0.00076	–0.00059	0.00041
	(–0.72)	(–1.33)	(0.18)	(–0.91)	(–0.63)	(0.60)
λ_3	–0.00054	–0.00054	–0.00041	0.00065	–0.00004	–0.00012
	(–1.54)	(–1.36)	(–1.19)	(1.67)	(–0.07)	(–0.37)
λ_4	–0.068	–0.048	–0.013	–0.077	–0.017	–0.071
	(–2.81)	(–1.81)	(–0.49)	(–3.00)	(–0.56)	(–2.88)

Table 7. Daily Risk-Return Tradeoff in Foreign Exchange Markets Based on the Range Volatility

The following regression is estimated with and without control variables to test the significance of the intertemporal relation between expected return and risk on currency:

$$R_{t+1} \equiv \alpha + \beta \cdot VAR_t^{range} + \lambda_1 \cdot FED_t + \lambda_2 \cdot DEF_t + \lambda_3 \cdot TERM_t + \lambda_4 \cdot R_t + \varepsilon_{t+1}$$

where $VAR_t^{range} = 0.361\left[\ln(P_t^{\max}) - \ln(P_t^{\min})\right]^2$ is Parkinson's (1980) range-based estimator of the daily integrated variance. The table presents the parameter estimates and their Newey-West (1987) t-statistics in parentheses.

Panel A. Daily Risk-Return Tradeoff without Control Variables

Parameters	EUR	JPY	GBP	CHF	AUD	CAD
α	–0.00051	–0.00022	–0.00038	–0.00053	–0.00053	–0.00048
	(–2.54)	(–1.11)	(–2.15)	(–2.28)	(–2.15)	(–2.67)
β	6.6224	4.6907	7.8004	6.8730	4.4630	8.4727
	(1.32)	(1.15)	(1.31)	(1.56)	(1.05)	(1.61)

Panel B. Daily Risk-Return Tradeoff with Control Variables

Parameters	EUR	JPY	GBP	CHF	AUD	CAD
α	0.00179	0.00250	0.00088	0.00238	0.00042	–0.00053
	(1.22)	(1.57)	(0.65)	(1.40)	(0.23)	(–0.37)
β	8.6053	5.0792	8.3969	7.3411	5.3794	9.2256
	(1.58)	(1.24)	(1.36)	(1.52)	(1.14)	(1.69)
λ_1	–0.00036	–0.00030	–0.00026	–0.00045	–0.00010	–0.00005
	(–1.26)	(–0.95)	(–0.93)	(–1.41)	(–0.25)	(–0.16)
λ_2	–0.00041	–0.00106	0.00015	–0.00049	–0.00038	0.00033
	(–0.57)	(–1.29)	(0.22)	(–0.59)	(–0.42)	(0.48)
λ_3	–0.00056	–0.00049	–0.00040	0.00070	–0.00019	–0.00009
	(–1.59)	(–1.25)	(–1.18)	(1.81)	(–0.40)	(–0.28)
λ_4	–0.067	–0.051	–0.012	–0.078	–0.026	–0.067
	(–2.77)	(–1.89)	(–0.45)	(–3.13)	(–0.87)	(–2.71)

Table 8. Daily Risk-Return Tradeoff in Foreign Exchange Markets with Libor Interest Rates

The following regressions with GARCH-in-mean, realized variance, and range variance are estimated to test the significance of the intertemporal relation between expected return and risk on currency:

$$R_{t+1} \equiv \alpha + \beta \cdot \sigma^2_{t+1|t} + \lambda_1 \cdot LIBOR_t^{US} + \lambda_2 \cdot LIBOR_t^{foreign} + \lambda_3 \cdot R_t + \varepsilon_{t+1},$$

$$R_{t+1} \equiv \alpha + \beta \cdot VAR_t^{realized} + \lambda_1 \cdot LIBOR_t^{US} + \lambda_2 \cdot LIBOR_t^{foreign} + \lambda_3 \cdot R_t + \varepsilon_{t+1},$$

$$R_{t+1} \equiv \alpha + \beta \cdot VAR_t^{range} + \lambda_1 \cdot LIBOR_t^{US} + \lambda_2 \cdot LIBOR_t^{foreign} + \lambda_3 \cdot R_t + \varepsilon_{t+1},$$

where $LIBOR_t^{US}$ and $LIBOR_t^{foreign}$ are the LIBOR rates for the US and the corresponding foreign country.

Panel A. GARCH-in-mean

Parameters	EUR	JPY	GBP	CHF	AUD	CAD
α	–0.0004	–0.0011	–0.0019	–0.0004	–0.0004	0.0006
	(–0.62)	(–1.82)	(–1.97)	(–0.31)	(–0.27)	(0.58)
β	6.7962	13.422	30.871	18.036	17.753	32.898
	(0.66)	(0.84)	(1.82)	(1.33)	(1.84)	(2.36)
λ_1	2.16×10^{-4}	2.86×10^{-4}	1.41×10^{-5}	3.30×10^{-4}	2.57×10^{-4}	1.95×10^{-4}
	(1.97)	(2.53)	(0.12)	(2.19)	(1.47)	(1.66)
λ_2	-2.61×10^{-4}	-8.94×10^{-4}	1.83×10^{-4}	-3.44×10^{-4}	-3.35×10^{-4}	-4.81×10^{-4}
	(–1.10)	(–1.32)	(0.78)	(–1.13)	(–0.78)	(–1.73)
λ_3	–0.055	–0.042	–0.008	–0.062	–0.010	–0.039
	(–2.22)	(–1.62)	(–0.31)	(–2.46)	(–0.36)	(–1.48)
γ_0	1.15×10^{-7}	1.64×10^{-6}	3.11×10^{-7}	2.64×10^{-7}	7.35×10^{-7}	2.44×10^{-7}
	(1.22)	(1.30)	(2.25)	(0.73)	(0.99)	(2.13)
γ_1	0.0300	0.0575	0.0408	0.0338	0.0563	0.0424
	(4.44)	(4.49)	(4.51)	(3.72)	(3.93)	(4.87)
γ_2	0.9672	0.8946	0.9476	0.9608	0.9287	0.9498
	(96.57)	(32.83)	(77.50)	(79.92)	(50.57)	(92.31)

Panel B. Realized Variance

Parameters	EUR	JPY	GBP	CHF	AUD	CAD
α	–0.00074	–0.00108	–0.00150	–0.00171	–0.00118	–0.00024
	(–1.08)	(–2.52)	(–1.61)	(–2.86)	(–0.77)	(–0.37)
β	17.558	10.272	10.499	18.730	–0.708	15.199
	(2.24)	(1.95)	(1.31)	(2.63)	(–0.11)	(1.69)
λ_1	2.5×10^{-4}	3.1×10^{-4}	-3.14×10^{-6}	4.5×10^{-4}	4.6×10^{-6}	1.4×10^{-4}
	(2.39)	(2.47)	(–0.03)	(2.96)	(0.026)	(1.00)
λ_2	-3.3×10^{-4}	-1.6×10^{-3}	2.2×10^{-4}	-6.5×10^{-4}	1.6×10^{-4}	-3.0×10^{-4}
	(–1.81)	(–2.01)	(0.90)	(–2.19)	(0.42)	(–1.03)
λ_3	–0.069	–0.048	–0.013	–0.078	–0.016	–0.073
	(–2.85)	(–1.79)	(–0.51)	(–3.10)	(–0.53)	(–2.91)

Table 8 (continued)

Panel C. Range Variance

Parameters	EUR	JPY	GBP	CHF	AUD	CAD
α	–0.00015	–0.00079	–0.00136	–0.00090	–0.00079	–0.00018
	(–0.26)	(–2.13)	(–1.49)	(–1.86)	(–0.52)	(–0.28)
β	8.181	5.558	8.416	7.400	5.249	9.761
	(1.49)	(1.29)	(1.37)	(1.51)	(1.03)	(1.77)
λ_1	1.9×10^{-4}	2.8×10^{-4}	-1.1×10^{-5}	3.5×10^{-4}	7.26×10^{-5}	9.5×10^{-5}
	(–1.92)	(2.32)	(–0.09)	(2.51)	(0.46)	(0.68)
λ_2	-3.4×10^{-4}	-1.3×10^{-3}	2.1×10^{-4}	-6.3×10^{-4}	1.08×10^{-6}	-1.9×10^{-4}
	(–1.86)	(–1.84)	(0.88)	(–2.20)	(0.003)	(–0.63)
λ_3	–0.068	–0.051	–0.012	–0.080	–0.025	–0.067
	(–2.82)	(–1.87)	(–0.47)	(–3.22)	(–0.85)	(–2.71)

Table 9. Testing Merton's (1973) ICAPM with a Common Slope Coefficient

Entries report the OLS and SUR panel regression estimates based on the following system of equations:

$$R_{i,t+1} = C_i + A \cdot \sigma_{im,t} + \varepsilon_{i,t+1},$$
$$R_{m,t+1} = C_m + A \cdot \sigma^2_{m,t} + \varepsilon_{m,t+1},$$

where $\sigma_{im,t}$ is the one-day lagged realized covariance between the exchange rate and the currency market. $\sigma^2_{m,t}$ is the one-day lagged realized variance of the currency market. A is a common slope coefficient on the lagged realized variance-covariance matrix. (C_i, C_m) denotes currency-specific intercepts for AUD, EUR, GBP, CAD, CHF, JPF, and the currency market. The last row reports the Wald statistics with p-values from testing the joint hypothesis that all intercepts equal zero: $H_0 : C_1 = C_2 = ... = C_6 = C_m = 0$.

	OLS Panel Regression		SUR Panel Regression	
	Intercept	t-stat.	Intercept	t-stat.
AUD	0.00076	4.69	0.00063	3.15
EUR	0.00097	5.24	0.00077	3.53
GBP	0.00062	3.82	0.00049	2.95
CAD	-0.00049	-3.24	-0.00041	-2.77
CHF	-0.00085	-4.72	-0.00066	-2.98
JPY	-0.00045	-2.79	-0.00032	-1.79
Market	-0.00078	-4.50	-0.00061	-3.35
	Slope	t-stat.	Slope	t-stat.
Risk Aversion	23.33	5.40	15.80	2.57
	Wald	p-value	Wald	p-value
H_0: Intercepts = 0	52.20	0.00	17.98	0.0121

Table 10. Testing Merton's (1973) ICAPM with Different Slope Coefficients

Entries report the OLS and SUR panel regression estimates based on the following system of equations:

$$R_{i,t+1} = C_i + A_i \cdot \sigma_{im,t} + \varepsilon_{i,t+1} ,$$
$$R_{m,t+1} = C_m + A_m \cdot \sigma^2_{m,t} + \varepsilon_{m,t+1} ,$$

where $\sigma_{im,t}$ is the one-day lagged realized covariance between the exchange rate and the currency market. $\sigma^2_{m,t}$ is the one-day lagged realized variance of the currency market. (A_i , A_m) denotes currency-specific slope coefficients on the lagged realized variance-covariance matrix. (C_i , C_m) denotes currency-specific intercepts for AUD, EUR, GBP, CAD, CHF, JPF, and the currency market. The Wald statistics with *p*-values are reported from testing the joint hypothesis that all intercepts equal zero: $H_0 : C_1 = C_2 = ... = C_6 = C_m = 0$. The last row presents the Wald statistics from testing the equality of currency-specific slope coefficients $H_0 : A_1 = A_2 = ... = A_6 = A_m$.

	OLS Panel Regression				SUR Panel Regression			
	Intercept	t-stat.	Slope	t-stat.	Intercept	t-stat.	Slope	t-stat.
AUD	0.00084	2.95	28.51	2.08	0.00072	2.85	21.01	1.90
EUR	0.00080	2.80	17.12	1.83	0.00071	3.13	13.62	2.06
GBP	0.00060	2.35	22.19	1.73	0.00030	1.38	4.60	0.46
CAD	-0.00063	-3.04	35.92	2.47	-0.00041	-2.23	15.67	1.36
CHF	-0.00082	-2.66	21.92	2.10	-0.00070	-2.80	17.32	2.26
JPY	-0.00048	-1.89	25.25	2.06	-0.00050	-2.30	26.29	2.77
Market	-0.00075	-3.08	21.92	2.31	-0.00059	-3.14	14.53	2.29
	Wald	p-value			Wald	p-value		
H_0: Intercepts = 0	51.40	0.00			15.15	0.0341		
	Wald	p-value			Wald	p-value		
H_0: Equal Slopes	1.41	0.9655			5.24	0.5131		

Figure 1. Rolling Regression Estimates from the Fixed-length Window of 250 Days

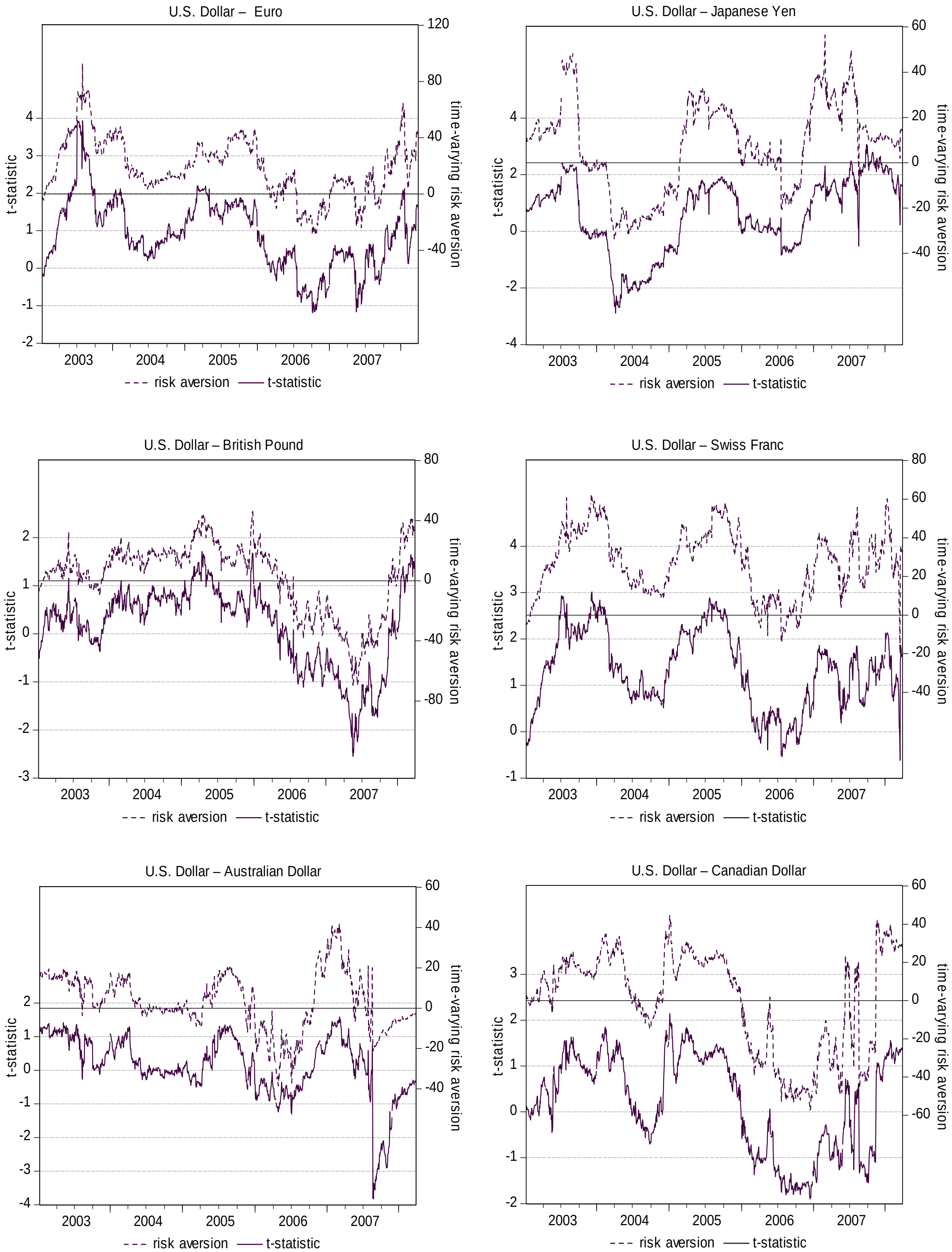
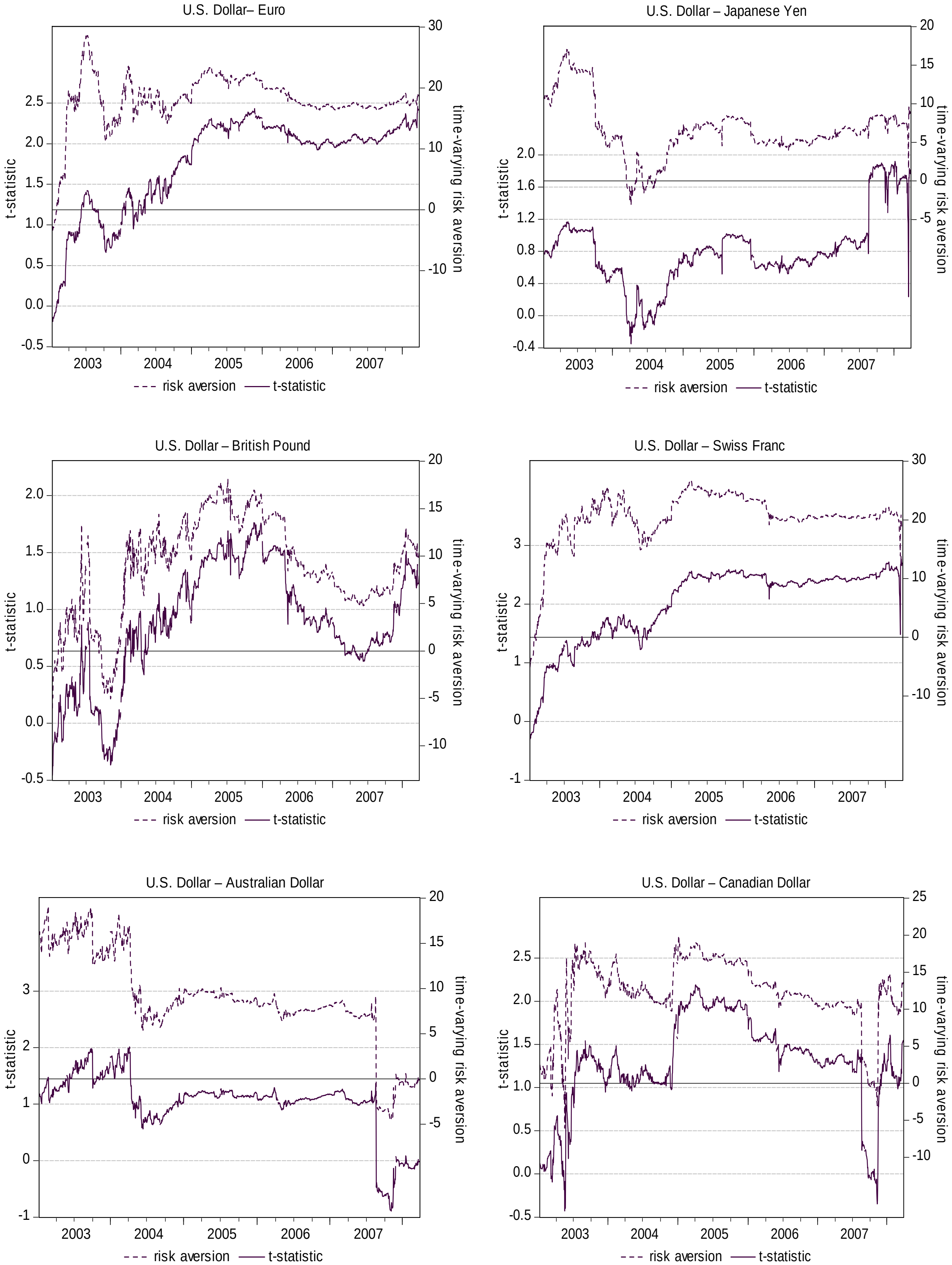


Figure 2. Rolling Regression Estimates from the Windows with Fixed Starting Point



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